RIS-Assisted 6G Networks: Challenges and Tradeoffs in Control Standardization

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***Abstract*—In contrast to the significant theoretical advancements in reconfigurable intelligent surfaces (RISs), relatively few studies focus on developing realistic models and prototype-based evaluations. Most current research emphasizes characterizing RIS devices, leaving network-level studies particularly scarce, despite their critical role in understanding RIS effects on network performance and supporting standardization—especially within the context of 6G. In this paper, we identify and investigate key characteristics of RIS-assisted links as a foundation for network-level operation. By exploring various use cases and associated challenges, we propose a control plane approach. Numerical results highlight certain limitations of RIS-assisted 6G networks from a control plane perspective.**

***Index Terms*—Network control, reconfigurable intelligent surface, RIS, standardization, 6G.**

I. Introduction

Reconfigurable intelligent surfaces (RIS) have emerged to be one of the key innovative technologies in upcoming 6G networks [1–3]. They allow for an easy and low-cost extension of the coverage area of a base station (BS). This is especially beneficial for wireless link technologies susceptible to high path loss or line of sight blocking, such as mmWave and sub-THz. While there has been a plethora of research on the theoretical aspects of RIS and physical demonstrators, comparably less attention was paid to formulating paths to deploy and integrate RIS into existing mobile networks and standards.

In this paper, we aim to share our vision of how the integration of RIS could look from the network control plane point of view. To this end, we first briefly outline the existing control schemes used in today's radio access networks (RANs) and the specific characteristics RIS-assisted links have. After that, we outline the major challenges these characteristics pose to the existing standards and mechanisms. Finally, we present a potential approach to architecting RIS-enabled wireless networks. We will outline the pros and cons of the proposed approach, including possible requirements for an upcoming standardization by 3GPP.

As outlined in [4], initial access of the user equipment (UE) to Base Station (BS) in 5G networks can experience delay due to the need for alignment between directional antennas at both the BS and UE. Several techniques, including exhaustive search, iterative search, and context-based algorithms, have been proposed to mitigate this. The optimal method depends on system parameters such as the target SNR. According to [5], beam sweeping is specified in the 5G standard as a procedure for identifying a new beam for data transmission. To improve beam sweeping efficiency, hierarchical codebooks are widely used in existing systems [6]. In networks with RIS, this presents a new set of challenges, especially in the context of control and management.

Recent work has addressed the control plane aspects of RIS-assisted networks [7–9]. Papers [7, 8] analyze the control signaling operations required to integrate RIS as a new wireless infrastructure element, both from two different perspctives; the former provides a systematic procedure for evaluating the impact of control operations on communication performance, while the latter focuses on distance-based signaling rate. Two new concepts are introduced in [9]: (i) wireless environment as a service, which leverages a RIS-empowered networking paradigm to balance conflicting connectivity objectives; and (ii) performance-boosted areas, representing spatially and temporally focused service provisioning zones enabled by RIS-based connectivity. Additionally, considering reliability in campus networks, [10] presents a model and optimization framework to maintain connectivity efficiently in a factory environment case study.

In this paper, we first identify the key characteristics of RIS-assisted links and their relevance to network control plane mechanisms. We then explore different use cases and the related challenges, proposing a control approach to address these challenges. Furthermore, we investigate the advantages and disadvantages of various control mechanisms. Finally, with numerical simulations, we highlight some current limitations of RIS-assisted networks.

II. RIS-assisted Link Characteristics

A typical application of the RIS, as depicted in Fig. 1, is to provide a virtual line-of-sight (vLOS) when the direct link between the BS and a UE is blocked. Let us now consider such a RIS-assisted wireless communication system that comprises a BS, multiple RISs, and several UEs. Let us assume that BS and RISs are static, while UEs can be static or mobile. Moreover, we adopt a far-field channel model and assume that each RIS serves one UE at a time due to system design considerations. As depicted in Fig. 2(a), we assume that there is a RIS controller

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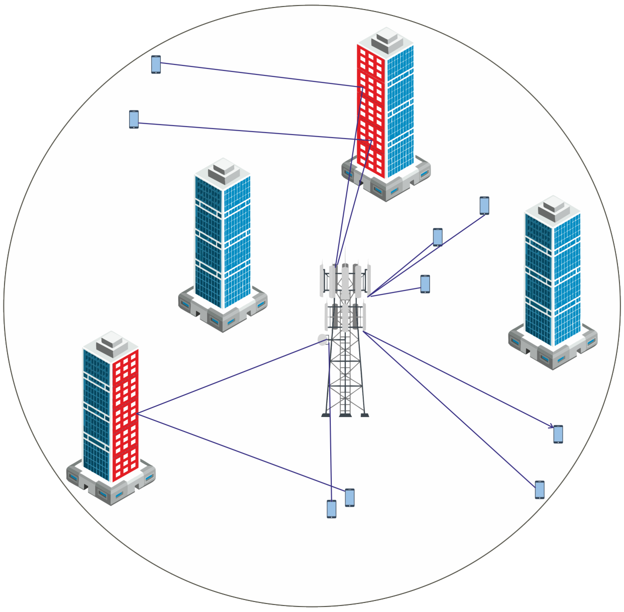

Figure 1. RIS-assisted wireless communication model. The red surfaces represent RISs placed on building facades to provide vLoS for the UEs.

located near the RIS, which provides intelligence for the RIS, including reconfigurations. Furthermore, to simplify the control process of the RIS and reduce overhead, we consider codebook-based beamforming for the RIS [11]. In simple terms, beams are selected from a predefined set of designed beams.

In this section, we elaborate on key characteristics of the RIS-assisted link and highlight how these differ from conventional wireless links. This analysis helps evaluate different control approaches and understand their impact on RIS-assisted 6G networks. The investigation will be conducted at a high level, focusing on the interdependencies between various layers of the protocol stack and their overall effect on system performance.

A. *Cascaded Channel*

As illustrated in Fig. 2(a), a RIS-assisted link, consists of two concatenated links—commonly referred to as a cascade channel—namely the BS-RIS and RIS-UE links. A signal transmitted by the BS travels through this cascade channel, encountering path loss twice, leading to what is known as double path loss [12]. This inherent characteristic of RIS-assisted systems results in lower overall channel gains than direct links.

In addition to double path loss, another key factor affecting the RIS-assisted channel gain is the RIS gain, which reflects the RIS ability to capture incident signal energy and redirect it toward the intended receiver. It is straightforward to show that larger RIS surfaces yield higher RIS gain and, consequently, higher RIS-assisted channel gain. While other factors—such as positioning the RIS within the near-field of the transmitter or receiver—can also influence channel gain, these aspects are outside the scope of this paper.

The key takeaway from this subsection is that using an RIS introduces additional path loss. While it offers benefits like overcoming non-line-of-sight conditions, it also requires a trade-off regarding reduced channel gain due to the cascade channel effect.

B. *Reconfiguration Time*

RIS performs beamforming by dynamically altering the phases of the reflected waves. The generation of these phase shifts can be realized using various technologies, each with its cost, energy consumption, and response time characteristics. The reconfiguration time, i.e., the time required to adjust the phase shifts, varies significantly across different technologies. For instance, some technologies, like Varactor diodes and PIN diodes, can achieve reconfiguration times in the range of a few nanoseconds [13, 14]. In contrast, others, such as liquid crystals (LC), have reconfiguration times that can extend beyond ten milliseconds [15].

Liquid crystal technology, in particular, offers advantages such as cost-effectiveness, scalability, low energy consumption, and the ability to provide continuous phase shifting. However, the relatively longer reconfiguration time associated with LC highlights the importance of carefully considering this factor in practical deployments. Regardless of the chosen technology, the reconfiguration time is a critical parameter and is often non-negligible, especially for high-capacity transmission links where rapid adjustments are essential to maintain performance.

C. *Beam Leap While Tracking*

In a mobile UE scenario, due to the movement of the UE, the device currently served via a RIS-assisted link may enter a blind spot of the RIS, as depicted in Fig. 2(c). In such cases, the BS may be able to serve the UE directly if the direct link is no longer blocked at the new location. Alternatively, if the direct link remains blocked, the system may need to switch to another RIS that can provide coverage in the UE's new location.

In either scenario, the next beam selected by the BS will likely be significantly different from the current one, as it may need to point in a completely different direction. This starkly contrasts conventional tracking methods, where beam sweeping typically occurs within neighboring beams to account for small movements of the UE. In RIS-assisted systems, the sudden shift in the required beam direction is a unique challenge, especially when switching between RISs or transitioning from RIS-assisted to direct links.

III. Control Plane Aspects

The previous section discussed the link-level challenges of establishing and maintaining RIS-assisted links. This section focuses on control plane aspects. To this end, we present several use cases, each of which introduces distinct requirements and open research challenges.

Let us assume that there is full synchronization between the BS, RIS, and UE. While a higher level of coordination can unlock more of RIS's potential benefits, leading to improved link management performance, it also results in increased control overhead and reduced compatibility with

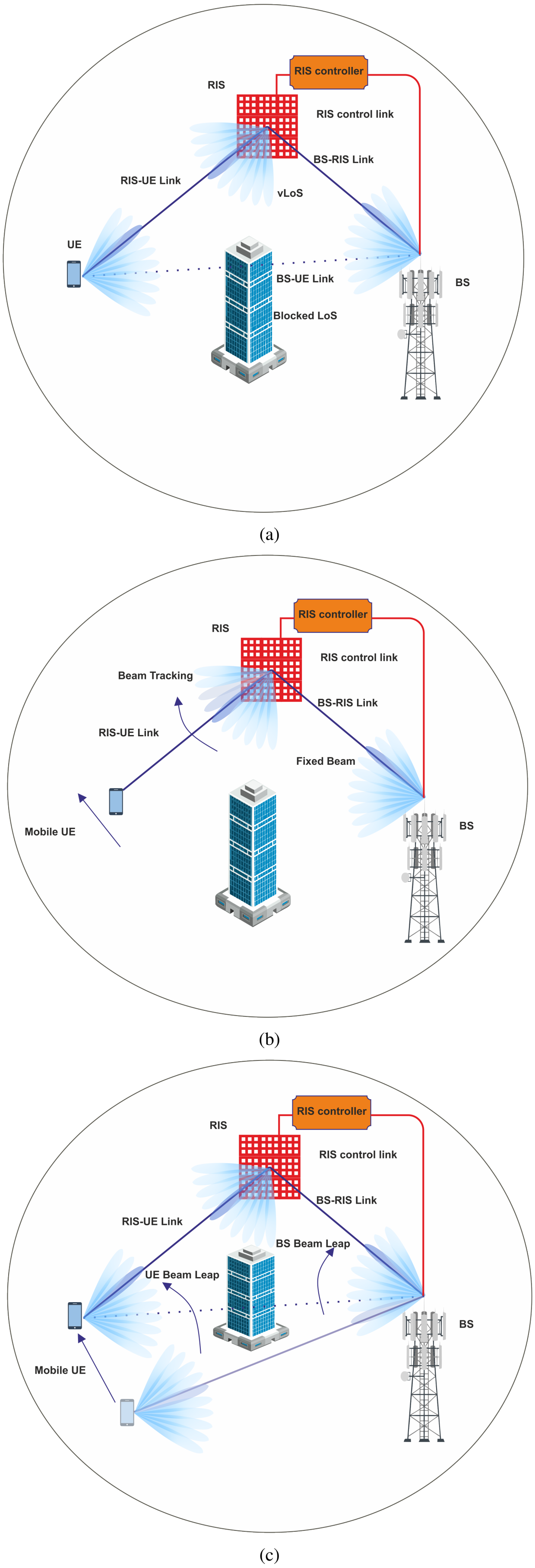

Figure 2. RIS-assisted link control mechanisms: (a) providing vLoS, (b) beam tracking for a mobile UE, and (c) BS and UE beam leaps.

existing network control protocols. Therefore, striking the right balance between coordination and control plane complextity and overhead is crucial for optimizing the performance and scalability of RIS-assisted systems.

A. Prospective Use Cases

We now present several use cases which explamlify various levels of interaction among a base station, RIS, and UEs. Considering the assumption that base stations and RIS are static, these use cases primarily focus on UE mobility and differ also in number of UEs, depending on the LoS blocking pattern.

For the continuous non-LoS scenario, all the communication is always intermediated by an RIS; thus, from the perspective of the BS, the signal always comes from the same direction or a small set of known directions, e.g., when the UE starts to be served by a different RIS. Table I summarizes the main challenges from the perspective of the RIS and the BS. Depending on the use case, the RIS needs to provide for switching among multiple UEs, which creates the need for the BS to handle a multiplexed communication pattern. Moreover, in the case of mobile UEs, tracking has also been added, as it is expected and required for the RISs to properly provision the link.

Table I
CHALLENGES FOR THE NON-LOS USE CASES.

UE	**Static**	**Mobile**
Single	None	Tracking (RIS)
Multiple	Switching (RIS) Multiplexing (BS)	Tracking (RIS) Switching (RIS) Multiplexing (BS)

In the case of an intermittent LoS scenario, we note that all known challenges from the non-LoS remain, but some new challenges are added to it. Table II summarizes these challenges. Since UEs can be connected via RIS or directly to the BS, both need to care for switching and tracking procedures. Moreover, if an RIS is serving a UE due to a temporary blocking and passes to have LoS with the BS, the UE's perceived position leaps in an unexpected direction, requiring a beam jump procedure at the BS.

Table II
CHALLENGES FOR THE INTERMITTENT LOS USE CASES

UE	**Static**	**Mobile**
Single	Leap (BS)	Tracking (RIS/BS) Leap (BS)
Multiple	Switching (RIS/BS) Multiplexing (BS) Leap (BS)	Tracking (RIS/BS) Switching (RIS/BS) Multiplexing (BS) Leap (BS)

B. Proposed RIS Control

In this subsection, we discuss the network control plane procedures when BS is fully coordinated with the RISs. In other words, we assume that BS has full knowledge of the location of the reachable RISs, and can provide the optimal beam directions toward these RISs.

We explore several key scenarios in this context, including the transition from direct BS coverage to RIS-assisted coverage (commonly referred to as link restoration), UE tracking via RIS, handling intermittent connection scenarios, and transition from a RIS-assisted link back to a direct link. Full coordination allows the BS to effectively manage these transitions and maintain seamless connectivity by leveraging its knowledge of the environment and RIS locations.

1) RIS-assisted Link Restoration Procedure: Link restoration refers to establishing a RIS-assisted link for a UE that was initially connected directly to the BS and is no longer within the BS's coverage zone due to mobility or environmental changes. In this scenario, based on prior information available to the BS, the BS can predict the degradation of the direct link. This prediction is made possible through prior knowledge of radio maps of the environment, allowing the BS to estimate its coverage area and anticipate the UE's trajectory toward a non-covered zone (e.g., blocked LoS). This awareness (i.e., anticipation) enables the network to preconfigure the RIS, ensuring it is ready in time to provide a seamless connection for the UE. Alternatively, the BS can continuously monitor channel quality and detect link degradation trends.

In either case, the BS triggers the network controller to initiate the link restoration or handover process. This involves either allocating an RIS to maintain the connection with the same BS or assigning the UE to another BS if it enters a new coverage area, which would lead to a handover. This paper focuses on the first case, i.e., link restoration.

The network controller first creates a pool of candidate RISs that can cover the UE at its current location. The network controller runs a resource allocation algorithm to select the most appropriate RIS based on factors such as the UE's service demand, priority, and resource availability. Once an RIS is allocated, the BS and the RIS controller are informed and configured accordingly, with beams directed to the appropriate locations. We assume there the UE's location is known. The accuracy of the location information depends on factors, such as the time elapsed since the last connection and the UE's mobility speed. Based on the available information shared with the RIS controller, the RIS may need to perform a beam sweeping over a smaller area (i.e., a smaller subset of beams) to restore the link to the UE.

From the BS's perspective, a key aspect of link restoration is the shift in beam direction—from the direct link toward the UE to the beam aimed at the RIS. This "beam leap" is critical to maintaining the connection as the UE moves into the RIS-assisted coverage zone. A similar beam leap also happens from UE's side (see Fig. 2(c)).

This process introduces control overhead and latency (depending on the underlying technology and control strategy). As a result, it can take a non-negligible amount of time to fully restore the link, which is critical to consider for maintaining performance in real-time applications. This non-negligible latency is a key difference between the conventional handover procedure and RIS-assisted link restoration. Specifically, RIS-assisted link restoration requires either the first approach, i.e., environmental awareness for proactive preconfiguration, which is not part of the current BS handover procedure, or the second approach, i.e., channel quality monitoring. Depending on the UE's speed and the RIS technology used, this second approach can result in brief connection gaps for the UE, which may be unacceptable in certain applications.

2) Beam-Tracking in RIS-assisted Link: In this scenario, we assume the BS-RIS-UE link has already been established through the link restoration procedure. However, as depicted in Fig. 2(b), when the UE is mobile, the RIS must continuously track the UE and adjust its beam accordingly. This is typically managed by the RIS controller, with feedback from the BS.

The procedure works as follows: As soon as the quality of the connection begins to degrade—either detected or predicted by the BS—the RIS controller is notified to adjust the beam. Unlike the initial link establishment (link restoration), where sweeping might involve a wide search, the adjustment is more localized here. The RIS sweeps through a few neighboring beams to find the one that offers the best signal quality or strength.

A key new distinction from what is common practice today, is that the BS here does not need to perform beam sweeping. Since the RIS remains fixed, the BS keeps its beam locked in the optimal direction toward the RIS. Only the beam from the RIS to the UE requires continuous updating to maintain link quality as the UE moves.

Furthermore, similar to conventional approaches, the number of selected neighboring beams depends on the UE distance, speed, and beamwidth. However, since the RIS typically has a larger surface area, its beamwidth is usually narrower compared to that of the BS. This narrower beamwidth requires consideration of more neighboring beams for the same distance and UE speed in conventional approaches.

3) RIS-assisted link to BS-Direct link: Due to the less favorable characteristics of RIS-assisted links compared to direct BS-to-UE links, the BS will attempt to re-establish a direct link whenever possible. One scenario for this is when the UE moves out of the RIS coverage area, either by moving beyond the coverage limits of the RIS or due to environmental blockages. Alternatively, even if the UE remains within the coverage zone of the RIS, it may be possible for the UE to connect directly to the BS from its new location. The network controller must transition from the RIS-assisted link to a direct BS-UE link in both scenarios.

In the latter case, regular probing is required to detect the existence of a viable direct link. Compared to transitioning from a BS-direct link to a RIS-assisted link, the evaluation stage for switching back to a direct link is less critical. This is because the transition to a direct link typically indicates an improvement in channel quality, while the opposite transition usually leads to a deterioration in link quality.

4) Intermittent LoS Connection: A challenging scenario must be considered when a mobile UE moves through an area with intermittent LoS connections. Frequent changes in connection status—between LoS and non-line-of-sight (nLoS)—within short time intervals complicate transitions. These changes require control signaling and involve reconfiguration time imposed by the RIS, making quick transitions difficult.

This rapid fluctuation in connection quality can lead to connection loss, as the link may not be re-established within the limited available time. One potential solution to this issue is to refrain from canceling the current connection immediately. Instead, the connection can be maintained for a short duration, depending on the network's agility in re-establishing a new connection, until the new connection is established.

Keeping the previous link active allows the system to seamlessly switch back to the prior connection state without further delay, even if the connection status changes during this period.

5) Link Backup - Multiconnectivity: As mentioned earlier, establishing a link involving a RIS takes time. If the connection initialization is not triggered early enough, the UE may experience periods of disconnection. This issue is particularly pronounced in channels with abrupt behavior, such as terahertz (THz) channels, where the sensing mechanism may not function effectively. A connection can drop to zero due to blockages, necessitating an agile mechanism that can respond quickly to establish a RIS-assisted link.

To address this, we propose a "link backup" strategy, in which a candidate resource (e.g., an RIS or another BS) is reserved for potential abrupt disconnections. In this approach, the resource allocation procedure described earlier operates in the background to identify suitable available resources based on the current network status. However, a significant drawback of this approach is the potential for over-allocation of resources in advance. This is not necessarily scalable and may only be feasible for high-priority UEs.

To further enhance performance, we can implement multi-connectivity. In addition to reserving resources for the UE to prepare for potential disconnections, we also follow a configuration and beam allocation scheme (as discussed in the UE tracking via the RIS section) to provide direct and RIS-assisted links simultaneously.

With this setup, as soon as the direct link is interrupted, we can seamlessly switch to the RIS-assisted link, which is already configured. This transition is completely seamless and occurs in negligible time. However, while this approach minimizes disconnection periods, it also entails the downside of over-allocating resources and introduces significant computational overhead for links that might not be frequently used.

IV. RIS-ASSISTED 6G NETWORKS

Having explored a range of potenatial challenges of integrating RIS into a radio access network, we now discuss more practical aspects of the same. While no commercial RIS is available as of today, let us assume for the sake of discussion that RIS reconfiguration time is 10 ms. This, along with the fact that introducing an additional network component will lead to additional delays, means that the strict latency requirements associated with 5G mobile standards that incorporate mmWave are even more challenging to guarantee. While in LTE handover interruption times of between 15 ms and 19 ms have been reported [16][17] in 5G and beyond, a zero ms [18] handover is envisioned. Given the intended use case for RIS mostly focuses on technologies that use highly directional beams such as mmWave or Sub-THz which only exist in 5G and onwards, link restoration will also have to be possible with zero delay. To achieve this, the RIS should be pre-configured to immediately serve a UE once it moves into its coverage area.

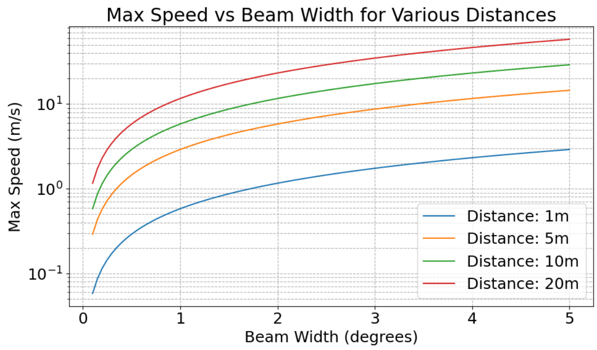

Figure 3. Maximum UE speeds depending on beam width.

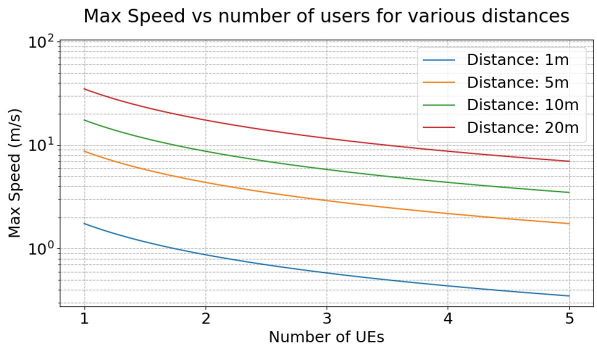

Figure 4. Maximum UE speeds depending on number of UEs.

An additional constraint that arises from the reconfiguration time is limitations on the maximum speed a UE can move while being covered by a RIS. While there are also limits associated with UEs moving inside the coverage areas of base stations, the RIS-related ones will likely be significantly more stringent. In addition to the reconfiguration time, the maximum speed also depends on the beam width and the distance of the UE to the RIS. We show the maximum speeds a UE could move, purely due to the reconfiguration time, in Fig. 3. The shown beam widths between 0.1 and 5 degrees cover mmWave and Sub-THz. Since these technologies will likely be mostly used indoors, we assumed distances of 1 and 10 meters. It should be noted that these speeds are only the theoretical limits. In practice, they will be lower as additional delays due to additional overhead from channel estimation, etc. The environment in which RIS is deployed and used must be carefully considered. While indoor environments, like smart factories with slow-moving AGVs, are suitable, outdoor environments, especially cars or trains, are not. Additionally, suppose a RIS serves more than one user using time multiplexing. As shown in Fig. 4, the number of users will reduce the maximum speed any single user can move because the reconfiguration delay occurs whenever switching between users.

V. Conclusion and Future Directions

In this paper, we addressed network-level challenges associated with integrating RIS as a key component, recognizing its critical role in enhancing network performance. We identified and examined the key characteristics of RIS-assisted links as foundational for network-level operation. Through various use cases and associated challenges, such as due to RIS reconfiguration time, we proposed a control plane approach. Our numerical results revealed certain limitations of RIS-assisted networks from a control plane perspective. Future research directions include a more comprehensive analysis of RIS applications across diverse control scenarios, from an integrated BS/RIS control (as discussed in this paper) toward an RIS-independent control plane.

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